International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-1, Issue-3, December 2014

Study of Voltage Stability Indices Suitable for Online Applications

Ch V V S Bhaskara Reddy

Abstract— **Modern power systems are operating close to their maximum loadability limit due to various economical, geographical, environmental and operational issues. Sometimes, these operating conditions lead to instability of power system. The instability in power systems is due to rotor angle issues or voltage related issues. In this article, two methods used to predict the voltage instability of power system are discussed. The methods discussed are Voltage Stability Risk Index (VSRI), and Improved Voltage Instability Monitoring Index (IVIMI). The VSRI and IVIMI are developed by using time series data and are suitable for online purposes. Study of these indices was carried out on Northern Region Power Grid 246-bus test system.**

Index Terms— **Improved Voltage Instability Monitoring Index, Power System Voltage Stability, Voltage Stability Risk Index.**

I. INTRODUCTION

Power system is one of the most complex man-made dynamical systems. Power system stability and control have always been challenging tasks. System configuration, operating conditions and various types of disturbances are some of the causes which will decide the type of analysis to study the instability in power systems. With the development of improved control and protective devices like static VAR compensators, generator fast speed governing systems and voltage regulators, power system transient stability limits have increased considerably. These improvements in the transient stability limits allowed more real power transfer over longer distances. In addition, the transmission and generation networks of the power system are being operated close to their maximum loadability limit due to economical, geographical and environmental reasons also. These factors have resulted in the increased reactive power demand in the system, leading to the difficulty of voltage control. This has contributed to the increasing number of voltage instability incidents worldwide that had led to the system voltage collapse [1].

Voltage stability can be defined as the ability of a power system to maintain steady acceptable voltages at all the buses in the system after being subjected to a disturbance from a given initial operating condition [2]. The problem of voltage collapse may be caused by the inability of power system to supply the reactive power or by an excessive absorption of reactive power in the system. The nature of loads also plays an important role in deciding the final state of the system. Other factors that strongly influence voltage instability and collapse include transformer On-Load Tap Changer (OLTC) dynamics and generator exciter current limits. To prevent the system from going into the state of voltage instability, it is required to know the closeness of a particular operating point to the point of voltage instability or stability boundary. In most of the incidences of voltage instability, which occurred worldwide, voltage collapse occurred after several minutes of initiation of the disturbance. Hence, most of the studies have considered the voltage stability as a static phenomenon.

A number of methods for voltage stability and voltage collapse prediction have been proposed in the literature. In [3], [4], voltage stability analysis using PV and QV curves was proposed and in [4], [5], voltage stability margin prediction using continuation power flow method is discussed. In the above two methods, a particular direction of change in load was assumed. But in practice, the change in load may not follow the assumed linear direction and the actual results may be different from those expected. Further, it is difficult to consider all possible load change directions. Voltage collapse indices based on load flow solution and system Y-bus were discussed in [6], [7], and those based on sensitivity of the load flow Jacobian were discussed in [8], [9]. The methods proposed in [6-9] need load flow solution for every load change and also need topology data to update Y-bus to incorporate the changes in the network configuration.

Almost all the methods discussed above are developed by considering measurements from Supervisory Control And Data Acquisition (SCADA) systems. The data refresh rate of these systems is slow, which makes it difficult to use these methods for online applications. On the other hand, with the development of newer technologies like phasor measurement systems, it become possible to get data as fast as 50 frames per second in 50Hz systems and 60 frames per second in 60Hz systems. With the use of the synchronized phasor measurements using Phasor Measurement Units (PMUs), it has become possible to build Wide Area Monitoring Systems (WAMS) and Wide Area Control Systems (WACS). The phasor measurement based voltage instability monitoring methods can be classified broadly into two categories, a) Local phasor measurement based methods and b) Global phasor measurements based methods.

The local phasor measurements based methods mainly use the Thevenin equivalent concept in the prediction of voltage instability [10], [11], [12], [13]. The methods track the Thevenin equivalent of the system based on local phasors. The parameter tracking is normally carried out over a measurement window in which the unknowns (Thevenin voltage and impedance) remain constant. These methods do not give the clear idea on the effects of various generator controls. Whereas, the global phasor measurements based methods give the wide area picture of the voltage stability [14]. These methods require system wide measurements to implement the algorithms.

Ch V V S Bhaskara Reddy is with the Department of Electrical Engineering, A U College of Engineering (A), Visakhapatnam – 530003, India.

In this work, study of two voltage stability monitoring indices suitable for online applications is carried out and the same are briefly presented in Section-B, Section-C presents results of the indices considered in this work, and conclusions of the work are presented in Section-D.

II. VOLTAGE STABILITY INDICES

Several articles have been published in the literature in the area of voltage stability assessment and control. Many researchers have suggested methods to detect the distance to the voltage instability from the current operating point. In this work study of two voltage stability indices suitable for real time applications are considered and brief description of the indices is presented in the following subsections.

A. Voltage Stability Risk Index (VSRI):

Voltage Stability Risk Index was proposed in [15]. It mainly involves three levels of calculations. First, moving average of the time series data over a particular window j is calculated by using measurements at N previous time instants i.

$$v_j^{ma} = \frac{\sum_{i=1}^{N} y_i}{N} \tag{1}$$

Using the moving average vj in Eqn. (1), percentage diversity di of the ith measurement is calculated by,

$$\%\ \text{diversity} = \frac{v_i - v_j^{ma}}{v_j^{ma}} \times 100 \tag{2}$$

Voltage Stability Risk Index zi is defined as,

$$z_j = \frac{\sum_{i=1}^{N} (d_j + d_{j-1}) \Delta t}{N \times 2} \tag{3}$$

where, vi= voltage measurement at ith time instant, v_j^{ma} = moving average of jth window, dj= diversity of the ith measurement for the jth window, zj = VSRI of the jth window.

B. Improved Voltage Instability Monitoring Index (IVIMI):

The basic definition of the proposed IVIMI [16], is as follows,

$$\text{IVIMI}_i = w_1(\text{i}) \times \frac{\text{VDR}_i}{\text{VDR}_{max}} + w_2(\text{i}) \times \frac{\text{CVD}_i}{\text{CVD}_{max}} \tag{4}$$

where, VDRi is the voltage deviation from its reference value at ith measuring instant, VDRmax is the maximum voltage deviation from its reference value, CVDi is the consecutive voltage deviation at the ith measuring instant, CVDmax is the maximum consecutive voltage deviation, w1(i) is the weight of the voltage deviation criterion at ith measuring instant, w2(i) is the weight of the rate of voltage change criterion at the i-th measuring instant.

In (4), one important factor is to find the values of VDRmax and CVDmax. The procedure used to find the various quantities of the eqn. (4) are as follows.

1) Calculation of VDR_i and VDR_{max}

At each measuring instant i, the voltage deviation from the reference or the nominal value is calculated as,

$$\text{VDR}_i = \text{V}_{ref} - \text{V}_i \tag{5}$$

In (5), V_{ref} is the reference value of voltage magnitude, which is the nominal voltage level or the base case value and V_i is the voltage magnitude at ith measuring instant. The maximum voltage deviation from its reference can be calculated as,

$$\text{VDR}_{max} = \min\{\text{V}_n\} - \text{V}_{min} \tag{6}$$

In (6), V_n is the set of nominal voltages of all the buses and V_{min} is the minimum voltage magnitude allowed in the system before initiating some control action like load shedding etc.

2) Calculation of CVD_i and CVD_{max}:

The difference between the voltages at two consecutive time instants indicates the rate of voltage decay/rise for a constant sampling time. Hence, the deviation in consecutive voltages at ith measuring instant can be written as,

$$\text{CVD}_i = \text{V}_{i-1} - \text{V}_i \tag{7}$$

As the system voltages move from stable state to unstable state, voltages at most of the buses will decay and therefore, the CVD value difference rises. Maximum consecutive voltage deviations (CVDmax) of the system can be obtained simply by tracking the maximum of the CVDi until any of the bus voltages falls below the Vmin, i.e. the CVDmax is dynamic until any of the bus voltages reaches Vmin. Once any of the bus voltages falls below the Vmin, the CVDmax is held at its value obtained just before going below the Vmin.

The weights w1 and w2 can be calculated using the algorithm proposed in [17].

IVIMI calculated at each load bus-p has been used to define Improved System-wide Voltage Instability Monitoring Index (ISVIMI) at *i*th measuring instant, as shown below.

$$\text{ISVIMI}_i = \max(\text{IVIMI}_i^p); \quad p \in \text{load buses set} \tag{8}$$

In the index defined in (4), numerator and denominator signify the measured deviation from its nominal state/base case and tolerable deviation of the system, respectively. As the measured deviation approaches the tolerable deviations of the system, the ISVIMI reaches numerical value 1.0 and gives an indication to the system operator to initiate some emergency control action like voltage control through generator's excitation system, shunt FACTS controllers or power flow control through series FACTS controllers and/or possibly as a last resort, load curtailment, to retain the system stability.

III. CASE STUDIES

Using the proposed voltage instability monitoring index, studies have been carried-out on the Indian North Regional Power Grid (NRPG) system. The reduced NRPG (400kV and 220kV buses only) network consists of 246 buses, 376 lines/transformers, 42 generating units and 40 shunt reactors [18]. Two cases have been considered to study the effectiveness of the proposed algorithm. The loads in the test system are replaced with ZIP load models [4],

$$\text{P} = [\text{a}(\text{V}/\text{V}_0)^2 + \text{b}(\text{V}/\text{V}_0) + \text{c}]\text{P}_0 \tag{9}$$

$$Q = [d(V/V_0)^2 + e(V/V_0) + f]Q_0 \qquad (10)$$

where, (a + b + c = 1) and (d + e + f = 1). Coefficients a, b, c are the proportions of ZIP components in the active power load, and coefficients d, e, f are the proportions of ZIP components in the reactive power load. P_0 and Q_0 are the real and reactive power demands at the nominal voltage V_0. Time series data for the two scenarios were generated using PSAT software [19] by considering two-axis flux decay dynamic model of generators with IEEE type DC-1 excitation system and over excitation limiters [4].

A. Case-I: Load Increase

In this case, real and reactive power loading at all the load buses are increased progressively at a rate of (0.006+j0.006) pu MVA per sec. The loading was started at time t=10s. With the said time-domain simulation, voltage collapse is observed at around 258s. Voltage critical buses identified based on IVIMI from the simulation are 156, 158, 173 and 174. Voltage variations at some of the critical buses are shown in Fig.1.

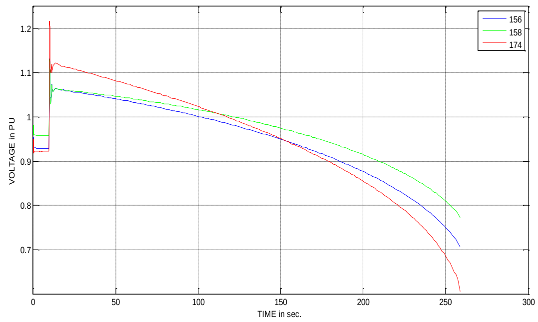

Figure 1: Critical bus voltages for load increase.

The results obtained using IVIMI and VSRI are shown in Figs. 2-3. The ISVIMI reaches unity in around 195s, whereas the system collapse occurred at around 260s. But the VSRI is constant almost near the collapse and changes abruptly just before the collapse.

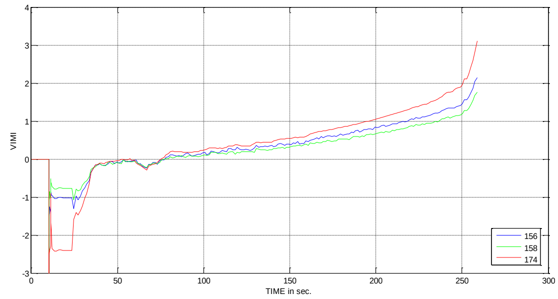

Figure 2: IVIMI plot for load increase

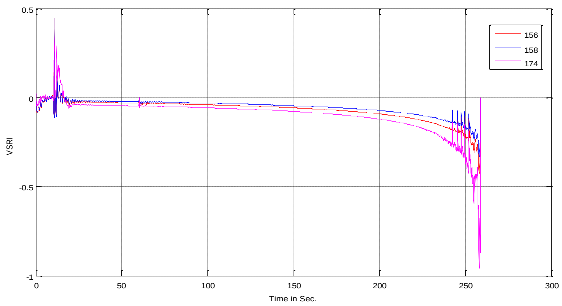

Figure 3: VSRI plot for load increase

B. Case-II : Line Outage

In this case, a line outage between buses 133 (Delhi) and 182 (Sahibabad in UP) is simulated at time t=5sec and simultaneously real and reactive power loadings are increased in Rajasthan at a rate of (0.003+j0.003) pu MVA per sec.

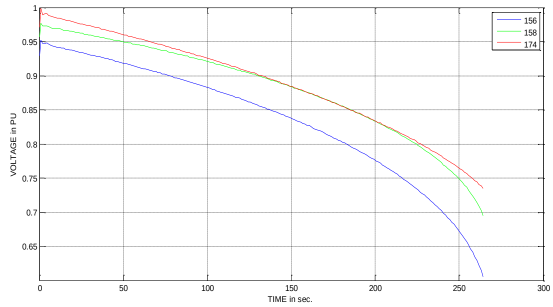

Figure 4: Critical bus voltages for line outage

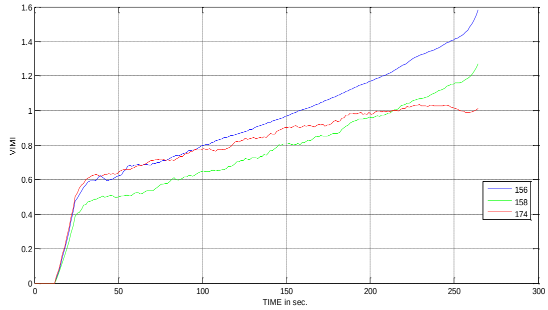

Figure 5: IVIMI Plot for line outage

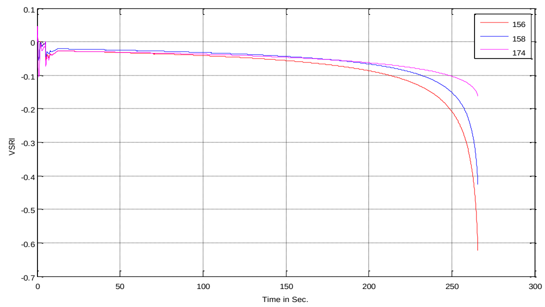

Figure 6: VSRI plot for line outage

Voltage critical buses, identified for this scenario, are 156, 158, and 174. Voltage variations at critical buses are shown in Fig. 4. The results obtained using the IVIMI and the VSRI are shown in Figs. 5-6, respectively. In this scenario, voltage collapse is observed at around 266s. The ISVIMI reaches unity in around 170s.

IV. CONCLUSIONS

In this paper, performance of the system-wide Improved Voltage Instability Monitoring Index (ISVIMI) and Voltage Stability Risk Index (VSRI) are carried out. The methods described for both the indices are simple and requires less computational efforts, which makes it suitable for online applications. The ISVIMI variation is more or less linear and changing its values with some slope. This sort of behavior of indices is more help full to the system operator in initiating some emergency or preventive controls. The VSRI is constant almost up to the system collapse and changes abruptly near the collapse. This type of indices may fail to assist the system operator in taking some control action. The above

conclusions were make based on the simulations carried out using time domain simulations for both the indices on the NRPG 246 bus test system under various disturbance scenarios leading to voltage collapse.

REFERENCES

[1] IEEE system dynamic performance subcommittee, "Voltage stability of power systems: concepts, analytical tools and industry experience," IEEE document 90TH0358-2-PWR-1990.

[2] Prabha Kundur et al., "Definition and classification of power system stability," IEEE Trans. Power Syst., vol. 19, no. 2, pp. 1387-1401, August 2004.

[3] Cladio Canizares et al., "Voltage stability assessment: concepts, practices and tools," IEEE/PES Power System Stability Subcommittee Special Publication, August 2002.

[4] Prabha Kundur, Power System Stability and Control, McGraw-Hill: Newyork, 1994.

[5] Venkataraman Ajjarapu, Computational Techniques for Voltage Stability Assessment and Control, Springer:Newyork, 2006.

[6] P Kessel and H Glavitsch, "Estimating the voltage stability of a power system," IEEE Trans. Power Delivery, vol. PWRD-1, no. 3, pp. 346-354, July 1986.

[7] V Balamourougan, T S Sidhu and M S Sachdev, "Technique for online predication of voltage collapse," IEE Proc.-Gener. Transm. Distrib., vol.151, no.4, pp. 453-460, July 2004.

[8] P A Lof, T Smed, G Andersson and D J Hill, "Fast calculation of a voltage stability index," IEEE Trans. Power Syst., vol.7, no.1, pp. 54-64, February 1992.

[9] B Gao, G K Morison and P Kundur, "Voltage stability evaluation using modal analysis," IEEE Trans. Power Syst., vol.7, no.4, pp. 1529-1542, November 1992.

[10] Khoi Vu, Miroslav M Begovic, Damir Novosel and Murari Mohan Saha, "Use of local measurements to estimating voltage-stability margin," IEEE Trans. Power Syst., vol.14, no.3, pp. 1029-1035, August 1999.

[11] Borka Milosevic and Miroslav Begovic, "Voltage-stability protection and control using a wide-area network of phasor measurements," IEEE Trans. Power Syst., vo.18, no.1, pp. 121-127, February 2003.

[12] Sandro Corsi and Glauco N Taranto, "A real-time voltage instability identification algorithm based on local phasor measurements," IEEE Trans. Power Syst., vol.23, no.3, pp. 1271-1279, August 2008.

[13] Yang Wang, Wenyuan Li, Jiping Lu, "A new node voltage stability index based on local voltage phasors," Electr. Power Syst. Res., vol.79, no.1, pp. 265-271, January 2009.

[14] Mevludin Glavic and Thierry Van Cutsem, "Wide-area detection of voltage instability from synchronized phasor measurements. part I: principle," IEEE Trans. Power Syst., vol.24, no.3, pp. 1408-1416, August 2009.

[15] Dong Joon Kim, Young Hwan Moon, Ho Yong Kim and Young Yoon, "System and method for calculating real-time voltage stability risk index in power system using time series data", United States Patent No. US 7236898 B2, Dt. June. 26, 2007.

[16] Ch V V S Bhaskara Reddy, S C Srivastava, Saikat Chakrabarti, "An Improved Static Voltage Stability Index using Synchrophasor Measurements for Early Detection of Impending Voltage Instability," Proceedings of the 17th National Power Systems Conference, IIT BHU, Varanasi, 12th-14th Dec., 2012.

[17] Sodhi, R. and Srivastava, S.C. and Singh, S.N., "A Simple Scheme for Wide Area Detection of Impending Voltage Instability," IEEE Trans. Smart Grid, Vol. 3, No. 2, pp 818-827, Jun. 2012.

[18] http://www.iitk.ac.in/ee/labs/lab_files/NRPG-DATA.pdf.

Ch V V S Bhaskara Reddy is working as Associate Professor in the Department of Electrical Engineering., A U College of Engineering (A), Visakhapatnam. He is a member of ISTE, IETE, and ISI. His research interest areas are Voltage stability, distribution systems, synchrophasor applications to power systems.